GROUP 1 TEST REPORT

SOLDER STUDY CONDUCTED ON APOLLO TELESCOPE MOUNT GYRO PROCESSOR

Contract No. NAS8-11684 95

MARTIN MARIETTA CORPORATION

SQ258888R

GROUP 1 TEST REPORT

SOLDER STUDY CONDUCTED ON APOLLO TELESCOPE MOUNT
GYRO PROCESSOR

Contract No. NAS8-11684 95

OR 9187

Copy

Prepared by:

D. F. Diel

D. F. Diel
Task Leader

Approved by:

R W Bradmiller

R. W. Bradmiller
Project Engineer

Martin Marietta Corporation
Orlando, Florida

FOREWORD

Martin Marietta Corporation, Orlando, Florida, is conducting a series of environmental tests under Contract NAS811864 on printed circuit assemblies for the Apollo Telescope Mount. These tests are divided into two groups. This report contains a description of the group 1 tests and their results. The group 2 tests will be described in a later report.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

TABLES

SUMMARY

A new thermal cycling machine and test have been developed that greatly reduces the time required to test new designs of printed circuit (PC) assemblies for resistance to solder joint cracking. Based on a 5 percent cracking level, the new test reduces the cycle time to approximately 2 percent of that required by earlier tests. Figure 1 is a photograph of the machine.

Table I is a concise presentation of the results of all Group I testing. It gives a brief description of the solder joint arrangements that are described fully later in this report along with the number of accelerated thermal cycles required to cause 10 percent of each type of arrangement to crack.

The results illustrate the vast improvement afforded by the new technique. For example, the standard NPC 200-4 solder joint on a TO-5 transistor kovar lead with a longer formed over section withstood only 25 thermal cycles. However, the same type of component with a soft rubber spacer, a copper tubelet over the end of the lead, and heavier solder withstood 3800 of the same thermal cycles. Test correlation data indicates that these 3800 accelerated cycles are equal to 10,500 one-hour air cycles from -55 to +125°C. There is little doubt these modified joints will meet 12,000 cycles of the less severe, -10 to +55°C, Apollo Telescope Mount (ATM) environment.

Several individual modifications, such as adding soft rubber pads to relays and transistors and changes in solder alloys and lead materials, afforded significant improvements in solder joint resistance to cracking. The test results also indicated the need for modifications in resistor and capacitor solder joints to increase their resistance to cracking.

TABLE I

Accelerated Thermal Test Summary

Solder Joint Type	Number of Cycles to 10% Cracked
Relay Pins, 0.030 in NI-FE, 0.093 in G10 Boards	
a) Standard Solder Joint, No Pad	400
b) Standard Joint With Soft Rubber Pad	900
c) No Pad, With Welded Flanged Tubelet	3300
Relay Pins, 0.030 in NI-FE, 0.062 in G10 Boards	
a) Plated Through Holes, No Pads	350
b) Plated Through Holes, Soft Rubber Pads	750
Resistors, 1/10 Watt, Hermetically Sealed	
a) Standard Joint 60/40 Solder	600
b) Standard Joint 96/4 Solder	950
Capacitors, Kidney Shape, (DM19), Standard Joint	800
Leads Only, 0.017-0.019 in	
a) Formed Over 0.100 in-0.150 in 60/40, NI-FE	800
b) Formed Over 0.100 in-0.150 in 60/40, Kovar	700
c) Formed Over Plus Tubelets, 60/40, Kovar	>3900
Transistors, TO-5 Size, 0.017-0.019 in Diameter Leads	
a) Standard Except Formed Over 0.1-0.15 in, 60/40, Kovar	25
b) Soft Rubber Pad, Formed 0.1-0.15 in, Tubelet, 60/40, Kovar	3800
c) Soft Rubber Pad, Straight-Squeezed, 96/4, Kovar	1900
d) Soft Rubber Pad, Flattened, Formed 0.1-0.15 in, 60/40, Kovar	1100
e) Soft Rubber Pad, Grad Form 0.1-0.15 in, 60/40, Kovar	1000
f) Soft Rubber Pad, Flattened, Formed 0.1-0.15 in, 96/4, NI-FE	1700
g) Soft Pad, "D" Loop, Tubelets, 60/40, Kovar	3300
h) Soft Pad, "D" Loop, Tubelets, 96/4, NI-FE	2800
i) Soft Pad, Tubelets, Formed 0.1-0.15 in, 96/4, NI-FE	3900
j) No Pad, Inverted, Formed 0.1-0.15 in, 60/40, Kovar	3000
k) No Pad, Inverted, Straight 1/16 in, 60/40, Kovar	1800

NOTE: These cycles should be multiplied by three to equate to one hour air cycles, -55 to +125°C. Explanation of abbreviations: G10 boards - glass reinforced epoxy boards. NI-FE is nickel-Iron leads; 60/40 - 60 percent tin/40 percent lead solder, 96/4 - 96 percent tin/4 percent silver solder.

*Accelerated test-use correlation factor (-100 to +200°F)

INTRODUCTION

The goal of 12,000 thermal cycles for the ATM greatly magnified the possibility of a critical solder cracking problem. A study program was therefore initiated to:

1. Develop an accelerated method for testing PC designs

2. Obtain correlation data with earlier solder testing results as well as the ATM environment

3. Develop and test PC designs that promise to meet ATM requirements.

I. DEVELOPMENT OF AN ACCELERATED TEST

A. EVALUATION OF METHODS

Earlier thermal cycling tests run at Martin Marietta on PC assemblies required that temperature changes be made gradually to avoid thermal shock. Approximately one hour was needed for a complete cycle from -55 to +125 to -55°C. Data was taken on many designs; this information is given in Martin Marietta Report OR 8813.

The requirements for a 12,000 thermal cycle goal from -10° to +55°C on the ATM Gyro Processor precluded the usefulness of such a slow test to prove out ATM designs. Therefore, three methods were evaluated. First, an automatic, dual chamber, air blast thermal cycling machine was monitored. It was found to be unsatisfactory because it required 8 to 10 minutes to saturate thermally a normal size (5- by 5-inch) PC board assembly that had been soaked at the opposite temperature extreme (-65 to +125°C). This evaluation showed that any air cycling machine would be too slow.

Second, small parts of PC assemblies (approximately two inches square) were dipped in hot oil at 300°F and liquid nitrogen at -320°F. Surprisingly, the solder joints withstood these thermal shocks and, after several dozen cycles, began developing the same type of solder joint deterioration and cracking that had been observed previously on gradual air cycling. However, the hot oil began softening the conformal coating, was messy to handle, and was difficult to inspect accurately.

Third, similar parts were alternately dipped in boiling water and isopropyl alcohol cooled by dry ice chunks. These materials maintained constant temperatures and did not affect the PC assemblies. The usual types of deterioration and cracking of the solder joints developed after a few score cycles. The small PC assemblies changed temperature in approximately 10 seconds. Larger assemblies required 20 to 30 seconds.

B. TEST EQUIPMENT

An automated cycling machine was built that would hold sixteen 5- by 5-inch PC assemblies (Figure 1). This machine rotates groups of four assemblies on each of four arms, dipping them alternately into a tank of boiling water and a tank of isopropyl alcohol cooled with dry ice. Each group of boards are in each tank 45 seconds; they then drain 15 seconds before entering the next tank.

Due to the urgency of the requirement for thermal cycling data for other temperatures, another machine was built that would automatically cycle four PC assemblies on each of two arms from one tank to another (Figure 2). One arm moves between one tank of boiling water and one tank

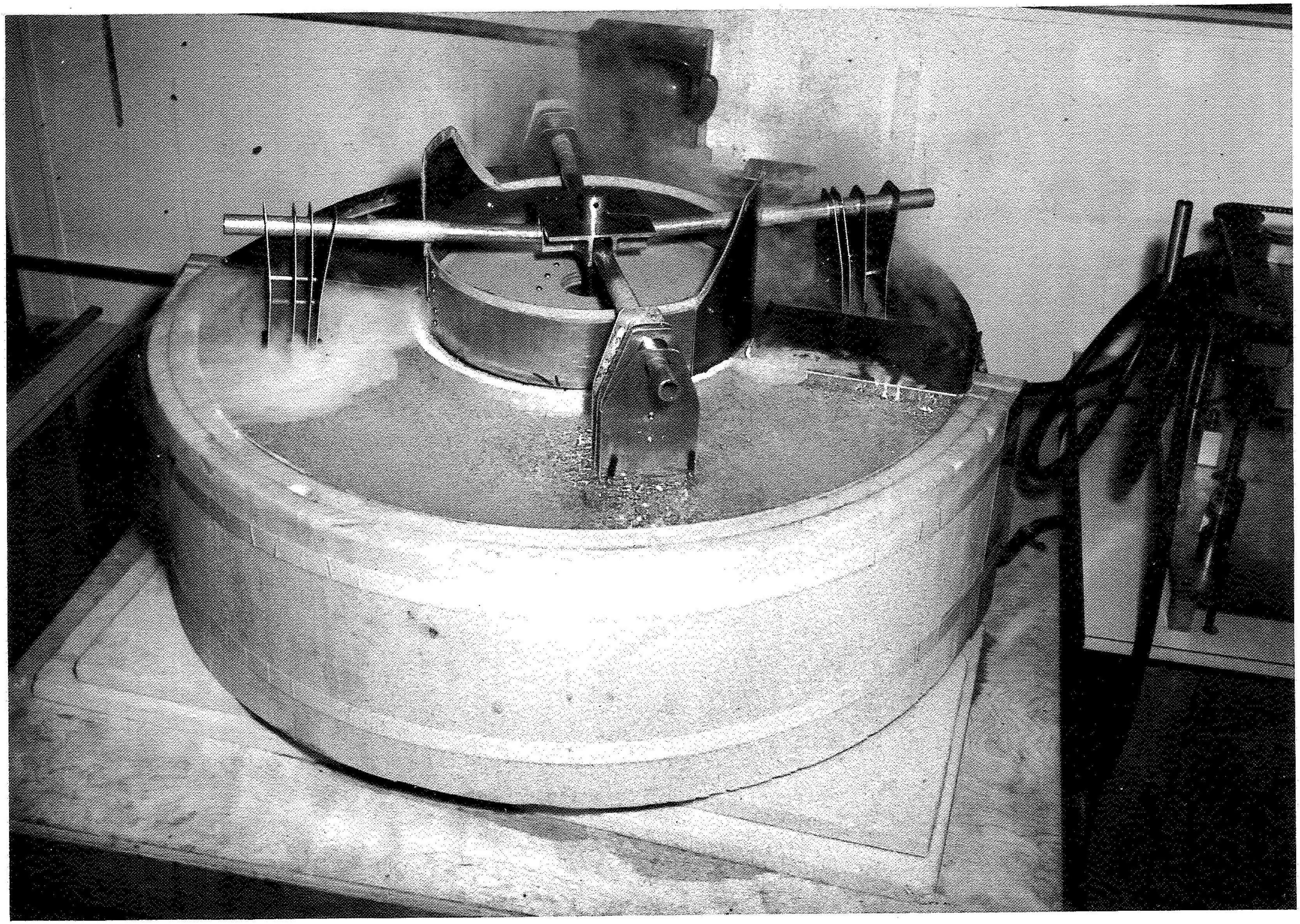


Figure 1. Rotary Test Machine

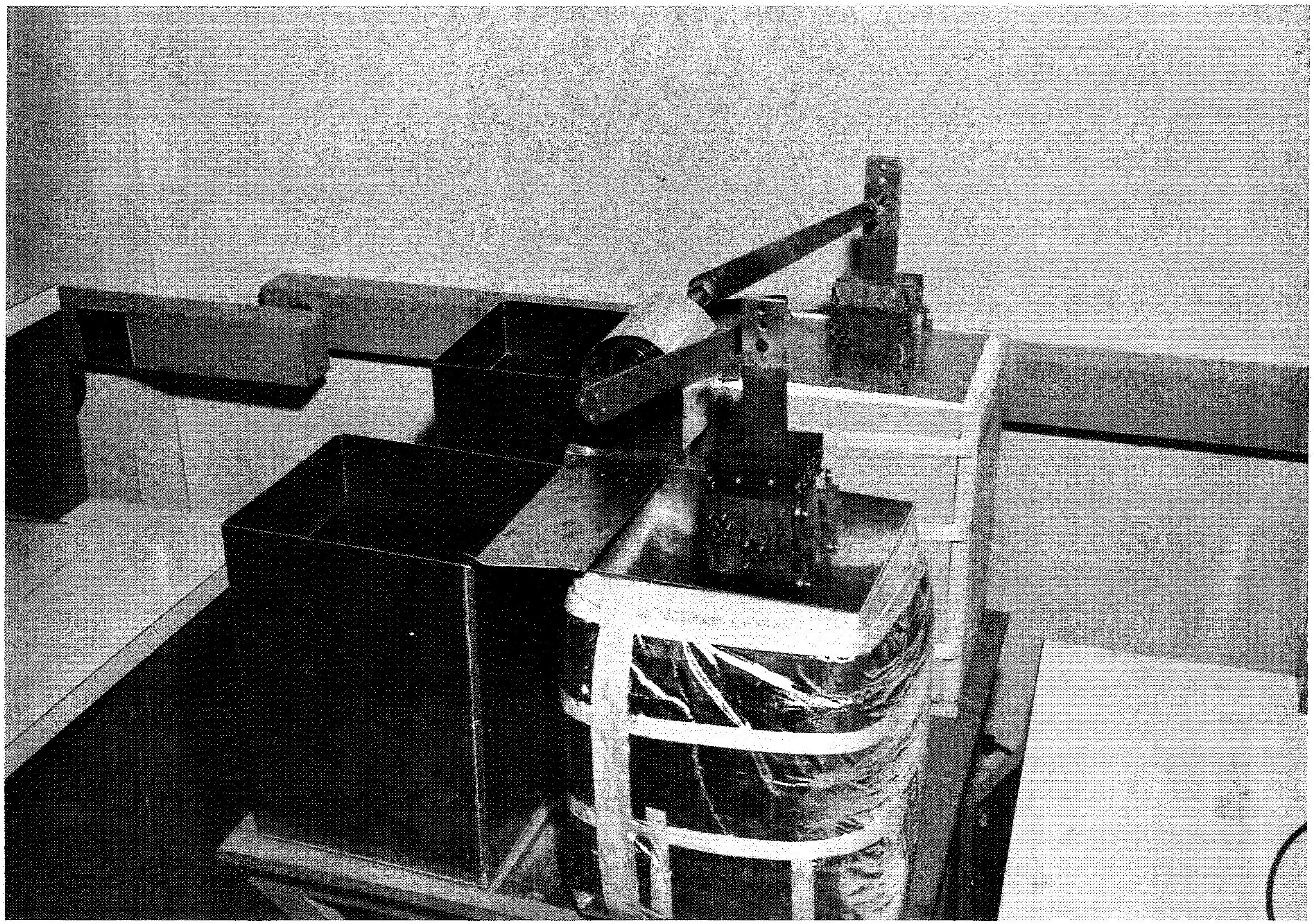


Figure 2. Two Arm Test Machine

of water at room temperature. The second arm moves between one tank of isopropyl alcohol cooled with dry ice and one tank of water at room temperature. The cycle is adjustable, but was set to dwell in each tank 45 seconds and transfer in 8 seconds.

II. TESTS

A. TEMPERATURE CORRELATION TESTS

1. Purpose.

Temperature correlation tests were conducted to prove the validity of the methods and test equipment described in Section I for the ATM printed circuit assemblies.

2. Test Specimens.

Six identical PC assemblies were constructed in the white room by a qualified solderer. Each assembly consisted of nine TO-5 transistors; each transistor had three gold plated kovar leads and were mounted on a 0.078 inch diallyl phthalate (DAP) transipad. The leads were formed over the 0.100 inch diameter copper pads between 0.050 and 0.100 inch and soldered with 60 percent tin 40 percent lead solder in accordance with NPC-200-4. The component side only was spray coated 0.008 inch thick with polyurethane PC-22 material. These assemblies were designated as temperature correlation boards and numbered one through six.

3. Test Procedure and Results

Boards one and two were thermally cycled on one of the arms through the tanks containing room temperature and boiling water. Boards three and four were thermally cycled on the other arm through tanks with water at room temperature and alcohol at -75°C. Boards five and six were placed on the rotating machine and cycled from $-75^{\circ}C$ to $+100^{\circ}C$. The temperature correlation test results are tabulated in Tables II, III, IV, and V.

Figure 3 shows the data from the above temperature correlation tests along with the results for the earlier air cycling tests on similar PC assemblies.

Table V gives a quick review of the data in the low percentage of solder joint cracking area, which is of prime concern. At the 5 percent level, the rotary accelerated test giving a $-75^{\circ}C$ to a $+100^{\circ}C$ excursion not only requires 2 minutes instead of 1 hour per cycle, but is four times as severe. Thus, the new method requires less than 1 percent of the time to develop the same deterioration as did the earlier air cycling method. The values given in Table V are at the 10 percent level and were obtained from tests on the rotary accelerated testing machine. These values therefore must be multiplied to equate them with the air cycling values; the multiplying factors are greater for equating these values to the number of actual environmental cycles the equipment will withstand.

TABLE II

Accelerated Automated Solder Test Results for Specimens TC-1 and TC-2 - Temperature Correlation*

Inspected at Number of Cycles	TC-1 +25°C, +100°C Number of Cracks	TC-2 +25°C, +100°C Number of Cracks	Percent of Joints Cracked (Total 54)
20	0	0	0
40	1	0	1.85
60	3	0	5.5
80	5	0	9.3
100	7	1	14.9
120	8	1	16.8
140	9	4	24.0
160	9	7	28.6
180	10	11	39.0
200	15	12	50.0
220	15	15	55.8
270	15	15	55.8
320	15	15	55.8

*Two arm liquid dip machine.

Note: Each temperature correlation board had 27 solder joints.

TABLE III

Accelerated Automated Solder Test Results for Specimens TC-3 and TC-4 - Temperature Correlation*

Inspected at Number of Cycles	TC-3 +25°C to -75°C Number of Cracks (27 Joints)	TC-4 +25°C to -75°C Number of Cracks (27 Joints)	Percent of Joints Cracked (Total 54)
20	0	0	0
40	0	0	0
50	1	0	1.85
70	2	0	3.7
90	4	0	7.4
110	5	0	9.3
130	6	0	11.1
150	6	0	11.1
160	7	0	13.0
180	8	0	14.9
200	8	1	16.8
250	8	1	16.8

*Two arm liquid dip machine.

TABLE IV

Accelerated Automated Solder Test Results for Specimens TC-5 and TC-6 - Temperature Correlation*

Inspected at Number of Cycles	Temperature Correlation Boards: TC-5 Standard Number of Cracks	TC-6 Standard Number of Cracks	Percent Cracked (Total 54)
20	0	4	7.4
40	5	6	20.4
61	13	10	42.5
81	14	13	50.0
101	14	18	59.0
154	14	22	64.4
201	14	24	70.0
251	20	25	83.0
312	20	26	85.0
450	20	26	85.0
566	20	26	85.0
766	20	26	85.0
884	20	26	85.0
984	Discontinued	Discontinued	Discontinued

*Rotary test machine (-75°C to +100°C)

Note: Each temperature correlation board had 27 solder joints.

TABLE V

Temperature Correlation Data

Cycle Data	Percent of Cracks				
	5	10	15	20	
1) Air Cycle, 45 minutes to 1 hour, -55 to +125°C	60	69	88	110	Cycles
2) Water-Alcohol, 2 minutes, -75°C to +100°C	15	25	32	38	Cycles
3) Water-Water, 2 minutes, +25°C to +100°C	62	83	108	130	Cycles
4) Water-Alcohol, 2 minutes, +25°C to -75°C	75	125	181	-	Cycles

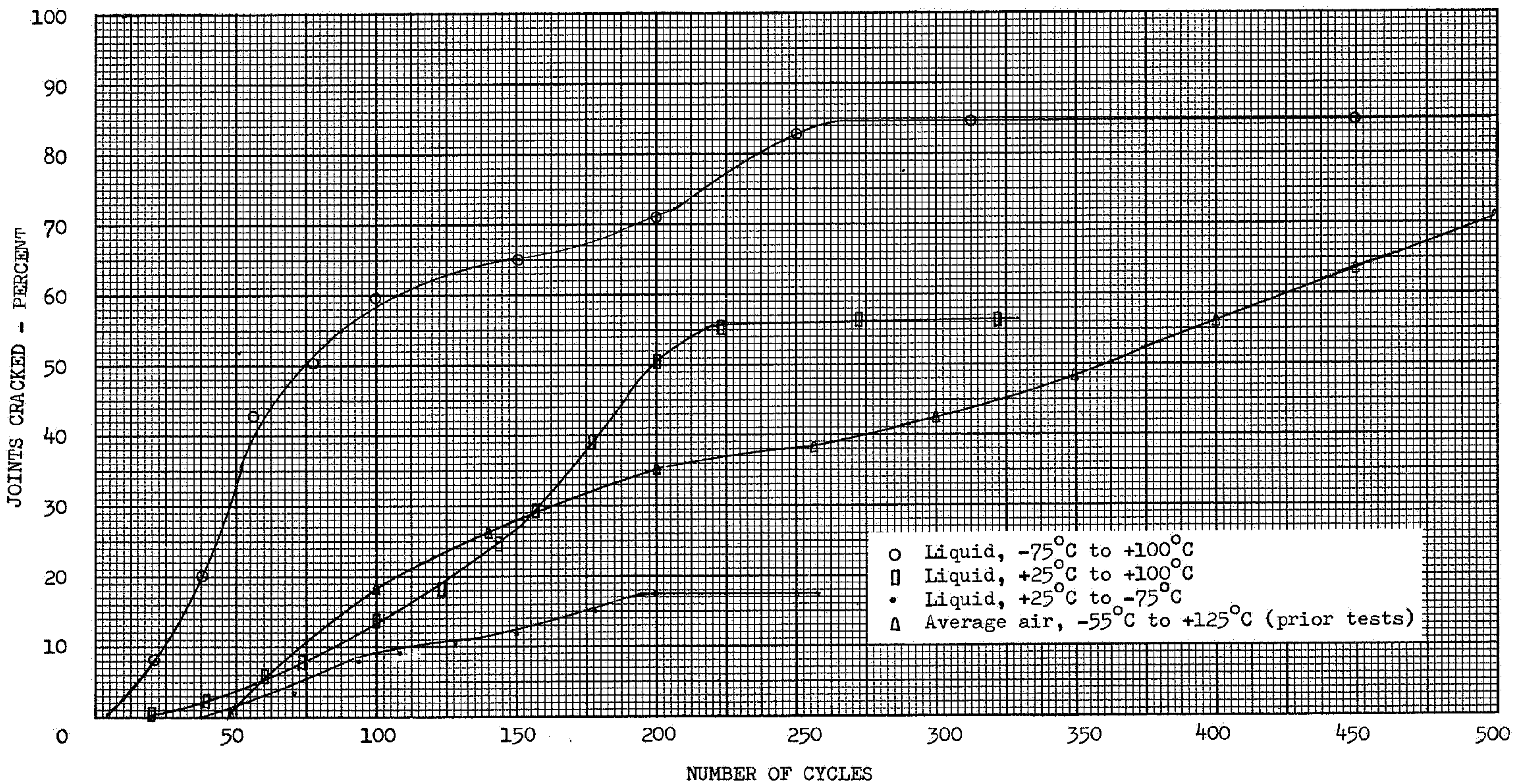


Figure 3. Temperature Correlation Curves for Standard Joints

B. SOLDER JOINT DESIGN TESTS

1. Purpose

The solder joint design tests described in this section were conducted to evaluate the comparative advantages of a selected group of solder joint arrangements and materials.

2. Test Specimens

Twenty solder joint arrangements were constructed under white room conditions by qualified personnel. Normal NASA conditions and procedures identical with those used on the control signal processor were followed, including inspections, except where deviations are specifically stated. All completed PC assemblies were inspected and then spray coated with 0.006 to 0.008 inch of polyurethane PC-22 conformal coating on the component side only. However, the coating did not cure properly on the soft rubber spacers. All of these assemblies were inspected during construction and throughout the testing by a qualified inspector accustomed to NASA quality requirements and familiar with the solder cracking problem.

All the PC assembly boards were laminated woven fiberglass impregnated with epoxy resins. All PC boards, except for the relay assemblies (described on page 13), were nominally 1/16 inch thick and approximately 5 inches by 5 inches. The relay assemblies were on 3/32 inch thick boards of the same material.

The following solder joint arrangements were placed on the PC boards:

1 PC Board L100 (five designs)

- a Nine TO-5 transistors, each having three gold-plated kovar leads 0.016 to 0.019 inch in diameter were soldered into the PC board. A soft neoprene, 40 shore A hardness, 1/16 inch thick spacer was placed between the PC board and the transistor body. Each lead was formed over 0.1 to 0.15 inch and a copper tubelet slipped over the lead and bonded with 60/40 solder (60 percent tin and 40 percent lead).

- b Nine TO-5 transistors, each having three gold-plated nickel-iron leads 0.016 to 0.019 inch in diameter were soldered onto the PC board. The same type neoprene spacers and tubelets used for a, above, were used in this assembly. A 96 percent tin/4 percent silver solder was used.

- c Three kidney shaped silvered mica capacitors (DM 19 type) were installed upright on the PC board. Each lead was formed over and bonded with a heavy 60/40 solder.

d Fifteen one-tenth watt, hermetically sealed glass resistors were installed in accordance with NPC 200-4, except that a heavier than specified solder joint was prepared. Standard 60/40 solder was used.

e Twenty-seven 0.016 to 0.019 inch diameter nickel-iron leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over the circuit pad 0.1 to 0.15 inch. Each lead was soldered to the pad with a heavy fillet of 60/40 solder.

2 PC Board L101 (four designs)

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene transipads. Each lead was brought through its hole and formed into a vertical loop approximately 1/16 inch in diameter with the end almost touching the lead where it came through the hole. The 60/40 solder was applied in a heavy fillet around the end of the lead and where it came through the hole, but the upper loop was left open. The lead and circuit pad were tinned using flux; however, the final soldering was done with solid 60/40 solder. This joint is defined as a "modified D loop."

b Nine TO-5 transistors, each having three gold-plated nickel-iron leads, were installed with soft neoprene transipads. Each lead was formed into a modified D loop, and the joints were made with 96 percent tin/4 percent silver solder.

c Fifteen one-tenth watt, hermetically sealed glass resistors were installed in accordance with NPC 200-4, except that a heavier than specified solder joint was prepared using 96 percent tin/ 4 percent silver solder.

d Twenty-seven gold-plated 0.016 to 0.019 inch diameter kovar leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over the circuit pad 0.1 to 0.15 inch. Each lead was soldered to the pad with a heavy fillet of 60/40 solder.

3 PC Board L102 (three designs)

a Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene spacers. The leads were brought through the PC board and formed over 0.1 to 0.15 inch. However, the lead was formed over a small wire such that the end of the lead touched the pad with a slight pressure and the lead did not form tightly across the edge of the hole. After the lead and pad were tinned and wicked off, a heavy joint was made with solid core 60/40 solder without flux.

b Nine TO-5 transistors, each having three gold-plated kovar leads were installed through the PC board. They extended out over the component side approximately 1/8 inch and were formed over 0.1 to 0.15 inch with tubelets installed over their ends. After tinning, a heavy joint of solid 60/40 solder was prepared.

c Twenty-seven 0.016 to 0.019 inch diameter, gold-plated kovar leads were installed through the PC board. They extended out the component side approximately 1/8 inch and were formed over 0.1 to 0.15 inch with tubelets installed over their ends. After tinning, a heavy joint of solid 60/40 solder was prepared.

4 PC Board L103 (three designs)

a Nine TO-5 transistors, each having three gold-plated nickel-iron leads, were installed with soft neoprene spacers. The leads were brought through the PC board and formed over 0.1 to 0.15 inch. However, the lead was formed over a small wire such that the end of the lead touched the pad with a slight pressure and the lead did not form tightly across the edge of the hole. After the lead and pad were tinned and wicked off, a heavy joint of 96 percent tin/4 percent silver was made.

b Nine TO-5 transistors, each having three gold-plated kovar leads, were installed with soft neoprene spacers. The leads were brought through the PC board 1/32 inch, squeezed flat, cut off, and soldered with a heavy fillet of 96 percent tin/4 percent silver solder.

c Three kidney-shaped silvered mica capacitors (DM 19 type) were installed upright on the PC board. Each lead was formed over and a heavy fillet of 60/40 solder applied.

The relay boards were prepared in the following manner:

1 Relay Board RB 1. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed. Each pin was soldered with heavy fillet of 60/40 solder in accordance with NPC 200-4.

2 Relay Board RB 2. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed with 1/32 inch soft rubber spacers, 40 shore A hardness, between the relay and the board. Each pin was soldered with a heavy fillet of 60/40 solder in accordance with NPC 200-4.

3 Relay Board RB 3. Five one-half size crystal case relays, each having eight 0.030 inch straight tinned nickel-iron pins, were installed. A copper, flanged tubelet was slipped over each pin, crimped, and resistance welded with the flange next to the circuit pad. Each pin was then soldered to the flanged tubelet and the circuit pad with 60/40 solder.

Six types of ATM PC boards were also tested. They were prepared in the following manner:

1 Boards 1 and 2. Five TO-5 transistors having gold-plated kovar leads were installed over 1/8 inch high, white, footed, polypropylene spacers. Each lead was formed over and soldered in accordance with NPC 200-4, except that a heavier 60/40 solder joint was used. One flat crystal case relay with 10 straight, 0.030 inch diameter, tinned, nickel-iron pins was also installed on each board with a 1/32 inch thick soft silicone rubber spacer; the spacer had a 40 shore A hardness. Each pin was soldered in accordance with NPC 200-4 with a heavy fillet of 60/40 solder.

2 Boards 3 and 6. Five TO-5 transistors with gold-plated kovar leads were installed over 1/32 inch thick soft silicone rubber, 40 shore A hardness, spacers, Each lead was formed over and soldered in accordance with NPC 200-4 procedures, except that a heavier 60/40 solder joint was made. One flat crystal case relay with 10 straight, 0.030 inch diameter, tinned, nickel-iron pins was also installed on each board with a 1/32 inch thick soft silicone rubber spacer; the spacer had a 40 shore A hardness. Each pin was soldered to the board in accordance with NPC 200-4 with a heavy fillet of 60/40 solder.

3 Boards 4 and 5 (designated GM-1 and GM-2)

a Six TO-5 transistors with gold-plated kovar leads were installed on 0.078 inch tall, diallyl phthalate spacers. The leads were formed over and soldered in accordance with NPC 200-4.

b Six TO-5 transistors with gold-plated kovar leads were installed in an inverted position with the top of the case against the PC board and the leads formed over (parallel to the sides of the case) and through the holes in the PC board. Each lead was soldered in accordance with NPC 200-4.

c Six TO-5 transistors with gold-plated kovar leads were installed in an inverted position with the top of the case against the PC board and the leads formed over (parallel to the sides of the case) and through holes in the PC board. The leads were cut off 1/32 inch above the board and soldered to the circuit pad with 60/40 solder.

3. Test Procedures and Results

a. Procedures

Each specimen was clipped by two alligator clips onto arms of of the rotary thermal cycling machine and run for 20 cycles; each cycle consisted of 45 seconds in each tank and 15 seconds of drain and transfer time. One tank contained boiling water and the other tank contained isopropyl alcohol cooled with chunks of dry ice.

The PC assemblies were removed and the solder joints inspected for cracks under magnifications up to 30 power after each 20 cycles for the first 100 cycles. The number of cycles between inspections was regulated by other conditions after a pattern was established. The inspection criterion was a visible crack in the solder. The severity of the cracking was noted and the location and type of cracking in unusual cases. A few typical solder joints were sectioned and microphotographed.

b. Results

The test results are presented in tabular form in Tables VI through IX and on Figure 3. Each table references the board number and has a brief description of the joint type that can be identified further in the description section.

Selected typical joints were sectioned and photomicrographed to show the extent of cracking and cracking patterns in various types of solder joints.

Photomicrographs A, B, and C in Figure 4 are typical of solder joints with 60/40 solder and a nickel-iron lead after only 3936 thermal cycles from -100°F to +200°F. Note in "A" how the solder has developed a lumpy appearance. Photograph "B" is a view of a further cut; both "A" and "B" are at 50 power magnification. The view of "C" is at 500 power magnification at the point in "B" shown by the arrow. Note that there is a good bond between the solder and the lead.

Figure 5 contains photomicrographs of a relay pin with a crimped, welded, flanged tubelet sectioned at two areas to show the extent of the cracking recorded after 3936 thermal cycles on the accelerated test machine. The "A" cross-section at the point of exterior crack shown by arrow is magnified 50 times; "B" is a 500 time magnification of the cracked area illustrated by the arrow in "A". Photograph "C" shows a lower cross-section of the same relay pin; the arrow shows the area near the end of the visible crack shown in "A". Note the void between tubelet and lead indicated by the large dark area. The "D" area is that shown by the arrow in "C" magnified 500 times; it shows that the crack did not continue down the tubelet. Actually, the crack is superficial and does no real harm, although it is a typical type of cracking on the crimped, welded, flanged tubelet on relay pins.

Figure 6 shows photomicrographs of a relay pin with a crimped, welded, flanged tubelet sectioned lengthwise at two areas to illustrate the second typical type of cracking that occurs during 3936 thermal cycles

TABLE VI

Accelerated Automated Solder Test Results for Specimens
L100 through L103 (Test Number 1B)*

Insp at No. of Cycles	L100 Trans Tube NI-FE No. Cracks	L100 Res 60/40 No. Cracks	L100 Caps No. Cracks	L100 Trans Tube Kovar No. Cracks	L100 Lead NI-FE Only No. Cracks	L101 Trans NI-FE No. Cracks	L101 Res 96/4 No. Cracks	L101 Trans Kovar No. Cracks	L101 Lead Kovar Only No. Cracks	L102 Trans Kovar No. Cracks	L102 Leads Kovar Tubes No. Cracks	L102 Trans Kovar SPL Form No. Cracks	L103 Trans NI-FE No. Cracks	L103 Caps No. Cracks	L103 Trans Kovar S. Flat No. Cracks	No. Cycle Insp
50	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	50
400	0	2M	0	0	0	0	1M	0	0	1M	0	0	0	0	0	116
516	0	2M	0	0	0	0	1M	0	1M	1M	0	0	0	1M	0	216
669	0	2M	0	0	0	3HM†	2M	0	2M	1M	0	0	0	1M	0	770
766	0	2M	0	0	0	3HM	2M	0	2M+5S	1M	0	2M	0	3M	0	888
884	0	4M	0	0	3M+1S	4HM	2M	0	2M+9S	1M	0	2M	0	3M	0	1088
984	0	5M	1M	0	3M+1S	4HM	2M+1S	0	2M+11S	1M	0	2M	0	4M	0	1244
1120	0	9M	1M	0	6M+1S	4HM	2M+2S	0	2M+12S	1M+3S	0	2M+2S	0	4M	0	1444
1238	0	11M	1M	0	12M+1S	4HM	3M+2S	0	8M+18S	13S	0	2M+9S	4M	6M	1M	1744
1438	0	15M	2M	0	13M+2S	4HM	3M+2S	0	10M+18S	24S	0	2M+23S	4M+1S	6M	1M+2S	1984
1594	0	18M	2M	0	16M+2S	5HM	3M+2S	0	10M+18S	25S	0	4M+23S	8M+1S	6M	6M+2S	2484
1794	0	19M	2M	1M	18M+2S	5HM	4M+2S	4HM	10M+18S	25S	0	4M+23S	12M+1S	6M	9M+7S	2984
2094	0	23M	3M	1M	20M+2S	5HM	6M+2S	4HM	10M+18S	25S	0	4M+23S				
2334	0	23M+1S	3M	1M	20M+2S	5HM	6M+2S	4HM	10M+18S	26S	0	4M+23S				
2834	0	23M+1S	3M	1M	20M+2S	12HM+1S	6M+2S	28HM	10M+18S	26S	0	4M+23S				
3334	0	23M+1S	3M	1M	20M+2S	12HM+2S	6M+2S	25HM+2S	10M+18S	26S	0	4M+23S				
3936	2M-1S	23M+1S	3M	3M	20M+2S	12HM+2S	6M+2S	25HM+2S	10M+18S	26S	0	4M+23S				

Severity of Cracking Code: M - Minor crack on less than 1/3 of joint, S - Serious crack on 1/3 to 2/3 of joint, C - Critical crack affecting over 2/3 of joint.

*Rotary test machine (-100°F to +200°F); test started 9/18/67.
†H symbol refers to heel of joint.

Note: Each group of transistors had 27 solder joints; each group of resistors had 30 solder joints; each group of capacitors had 6 solder joints; each group of 4 leads had 27 solder joints.

TABLE VII

Accelerated Automated Solder Test Results for Relay Board Specimens (Test Number 1A)*

Inspected at Number of Cycles	Relays on Boards		
	No. 1 Rubber Pads Number of Cracks	No. 2 Standard Number of Cracks	No. 3 Eyelets† Number of Cracks
20	0	0	0
40	0	0	0
61	0	0	0
81	0	0	0
101	0	0	0
154	0	0	0
201	0	0	0
251	0	0	0
312	0	0	0
450	0	8S	0
566	0	8S	0
766	0	8S+2M	0
884	0	8S+4M	0
984	2S	8S+6M	0
1120	11S	15S+6M	0
1238	25S	21S+6M	0
1438	34S+6M	28S+12M	0
2094	Discontinued	Discontinued	0
3334	-	-	4M
3936	-	-	4M

Severity of cracking code:

M - Minor crack on less than 1/3 of joint
S - Serious crack on 1/3 to 2/3 of joint
C - Critical cracking affecting over 2/3 of joint

* -75°C to +100°C
†Crimped, welded, flanged tubelet

Note: Each relay board had 40 solder joints

TABLE VIII

Accelerated Automated Solder Test Results for Specimens GM-1 and GM-2 (ATM Boards 4 and 5)*

Inspected at Number of Cycles	GM-1 Board (No. 4)			GM-2 Board (No. 5)		
	Trans Reg Pad 18 Std Kovar No. Cracks	Trans Inverted 18 Form Std Kovar No. Cracks	Trans Inverted 18 Straight Kovar No. Cracks	Trans Reg Pad 18 Std Kovar No. Cracks	Trans Inverted 18 Form Std Kovar No. Cracks	Trans Inverted 18 Straight Kovar No. Cracks
20	0	0	0	0	0	0
50	0	0	0	0	0	0
100	0	0	0	0	0	0
200	0	0	0	0	0	0
300	0	0	3M	0	0	0
634	0	1M+1S	3M	0	0	0
1134	2M	5M+1S	3M	0	3M	0
1594	3M	6M+1S	12M+2S	0	4M	13S
1736	5M	10M+1S	14M+2S	2M	11M	13S
1794	6M	10M+1S	14M+2S	2M	11M	15S
2044	7M	11M+1S	3M+12S	2M	12M	15S
2244	9M	11M+1S	3M+12S	2M	12M	15S
2544	11M	11M+1S	3M+12S	2M	12M	15S
2784	13M	11M+1S	3M+12S	2M	12M	15S
3054	15M	13M+2S	3M+12S	2M	12M	15S
3556	18M	15M+3S	6M+12S	2M	13M	3M+15S

M - Minor crack S - Serious crack over one-third of periphery of lead

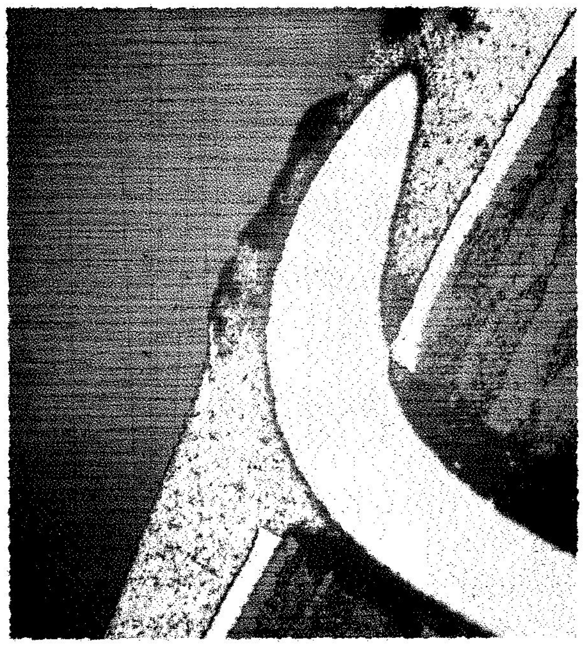
*Rotary test machine (-100°F to +200°F)

TABLE IX

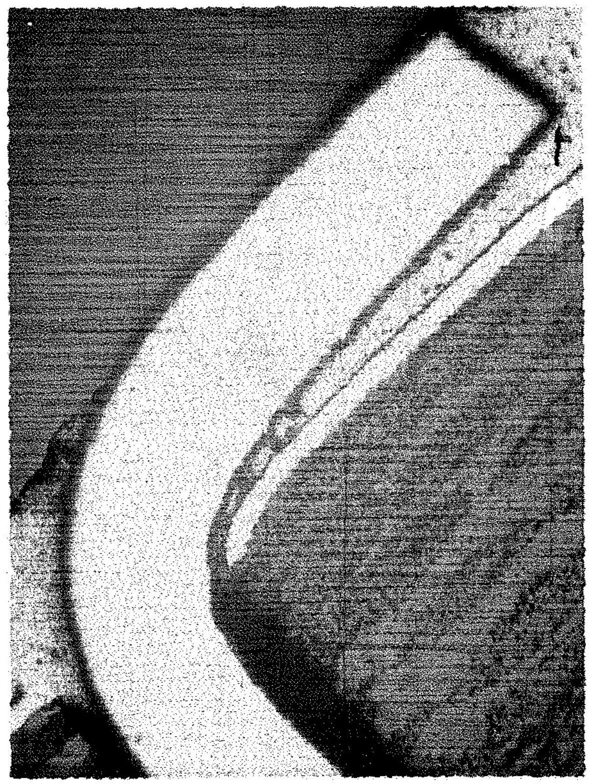
Accelerated Automated Solder Test Results
for ATM Specimens 1, 2, 3, and 6*

Inspected at Number of Cycles	ATM(No. 1) Board		ATM(No. 2) Board		ATM(No. 3) Board		ATM(No. 6) Board	
	Trans Polyp Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Polyp Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Rub. Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks	Trans Rub. Pad 15k HS No. Cracks	Relay Rub. Pad 10 N-F HS No. Cracks
20	0	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	0
200	0	0	0	0	0	0	0	0
300	0	0	3M	0	0	0	0	0
450	0	0	3M	0	0	0	0	0
701	8M+1S	2M+2S	15S	10S	0	0	0	0
800	9M+1S	2M+2S	15S	10S	1S	10S	3M+2S	0
1216	9M+2S	2M+2S	15S	10S	1M+1S	10S	3M+2S	6S+4LP†
1314	9M+3S	2M+7S	15S	10S	1M+2S	10S	3M+2S	6S+4†
1517	9M+3S	2M+7S	15S	10S	3M+2S	10S	3M+2S	6S+4†

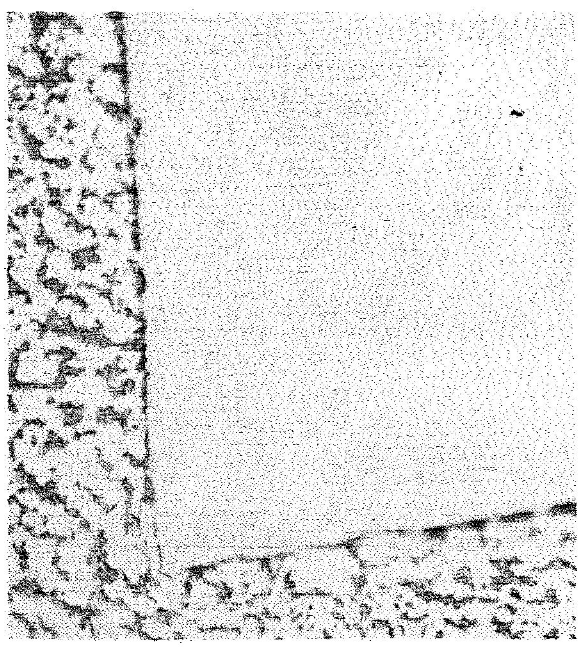
M - Minor crack
S - Serious crack over one-third of periphery of lead
*Rotary test machine (-100°F to +200°F)
†LP - lifted pad on PC



A
Magnified image copied at 85 percent

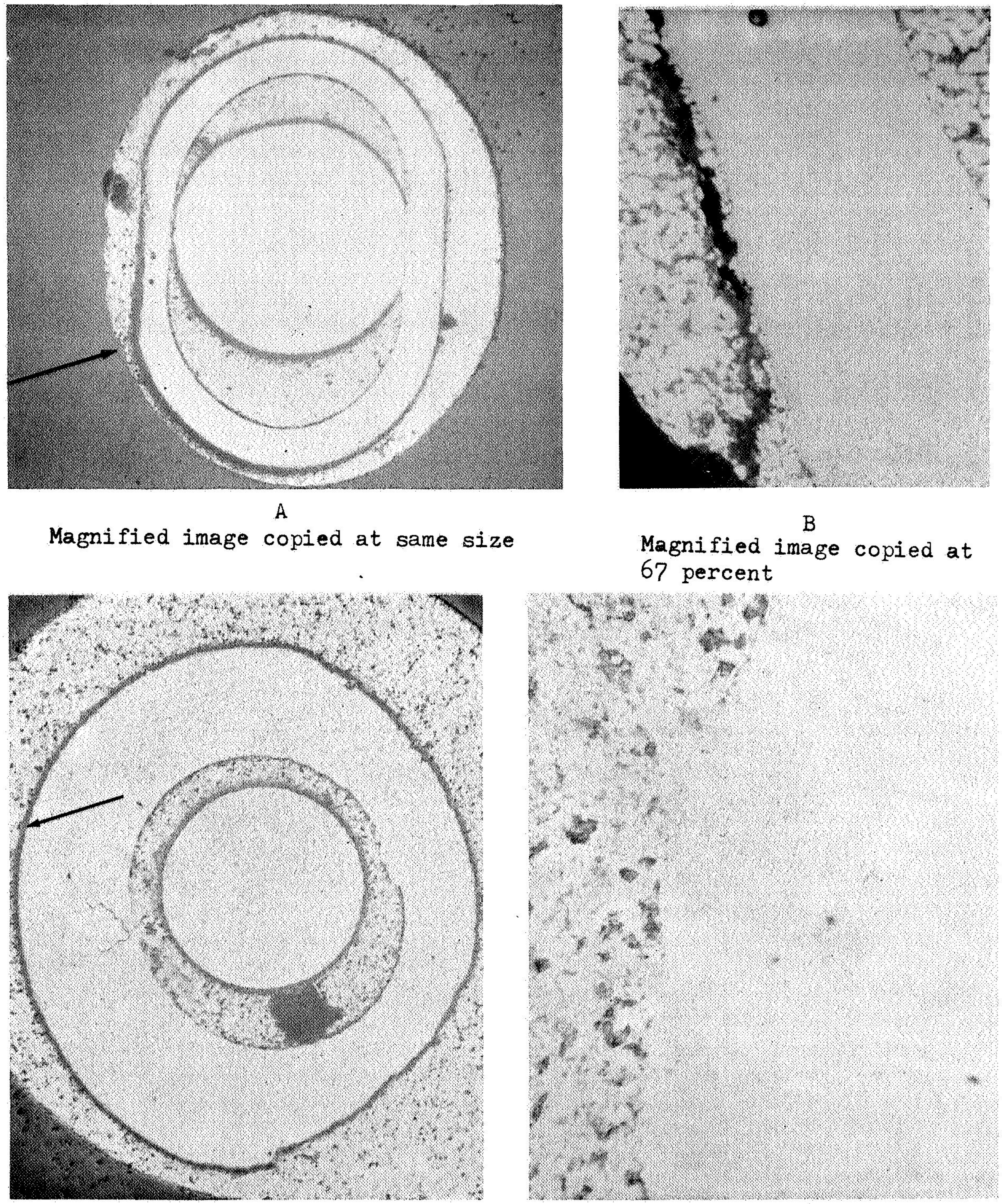


B
Magnified image copied at 90 percent



C
Magnified image copied at 85 percent

Figure 4. Typical Joint with 60/40 Solder and Nickel-Iron Lead after 3936 Cycles from -100°F to +200°F



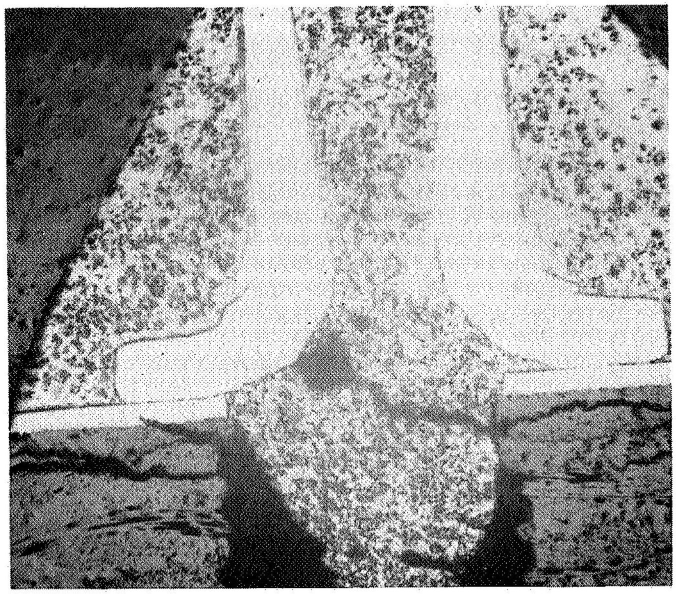
A
Magnified image copied at same size

B
Magnified image copied at 67 percent

C
Magnified image copied at 85 percent

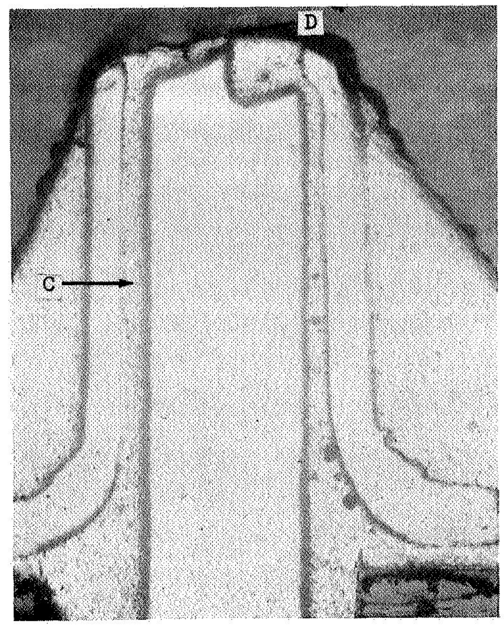
D
Magnified image copied at 85 percent

Figure 5. Cross-Section of Solder Joint with Relay Pin and Copper Tubelet after 3936 Cycles from -100°F to +200°F



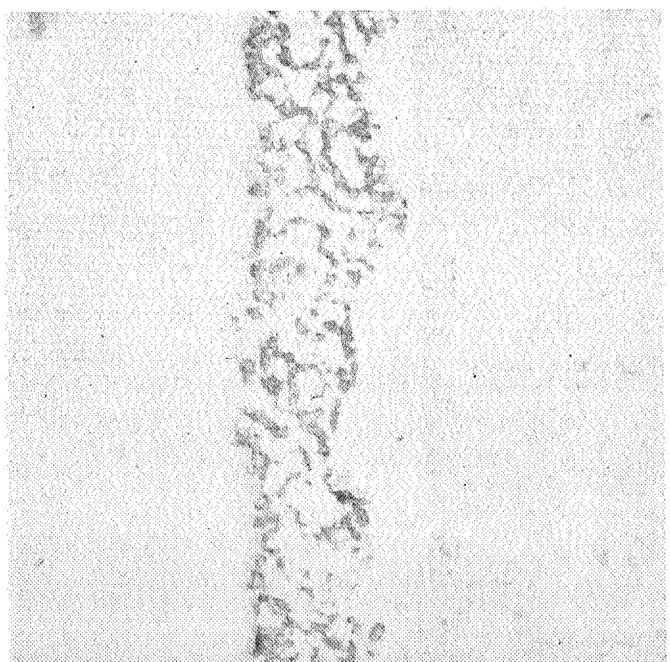
A

Magnified image copied at 87 percent



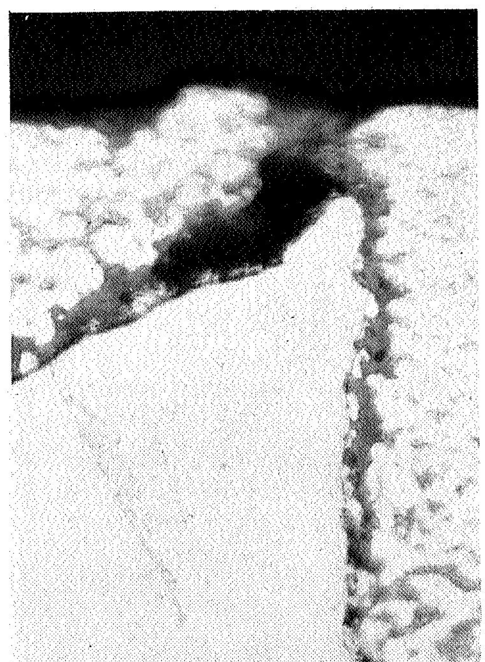
B

Magnified image copied at 77 percent



C

Magnified image copied at same size



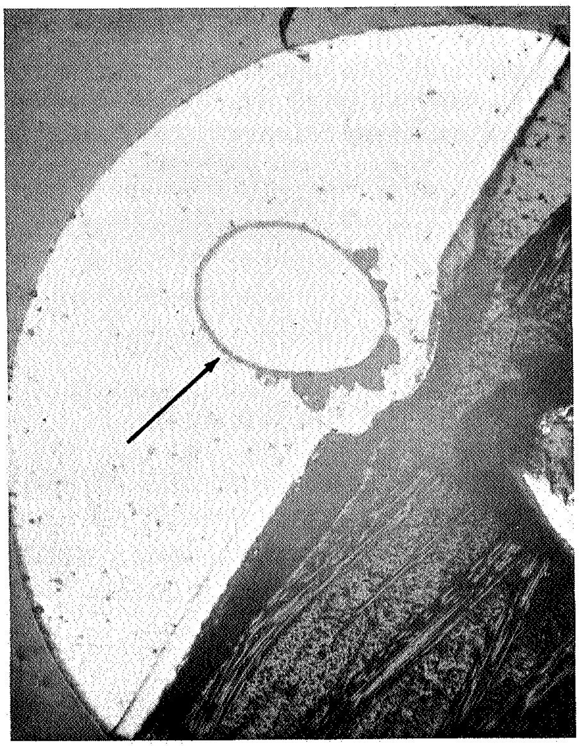
D

Magnified image copied at same size

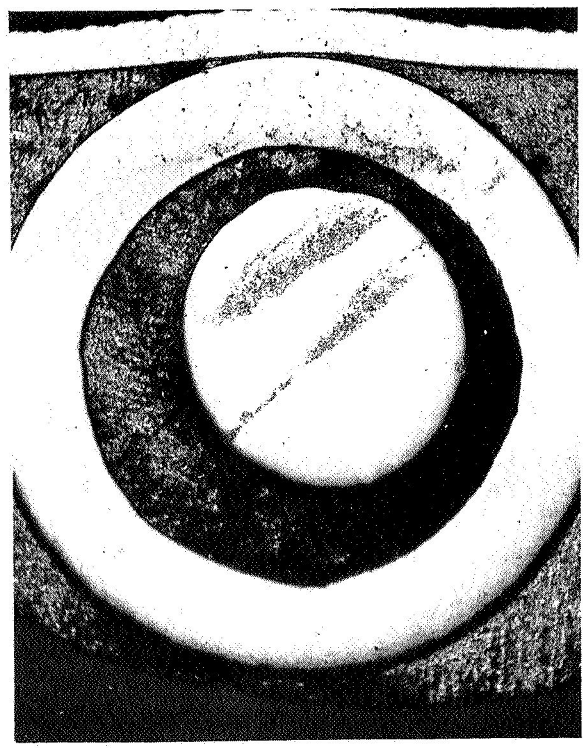
Figure 6. Lengthwise Section of Solder Joint with Relay Pin and Copper Tubelet after 3936 Cycles from -100°F to +200°F

on the accelerated testing machine. Note that the cracking is very localized and superficial. Photograph "A" shows only the tubelet; note the crack in the solder in the hole section of the PC board at 50 times magnification. Photograph "B" shows the central cross-section of the relay pin, tubelet, and solder. Note that the arrow at the end of the pin shows a crack that occurred where the pin was clipped off. Photograph "C" is a magnified (500 times) view of the bond between the relay pin and the solder showing that a good metallurgical bond existed. Photograph "D" is a 500 times magnification that shows the extent of the localized cracking where the relay pin was clipped off; this is a typical crack.

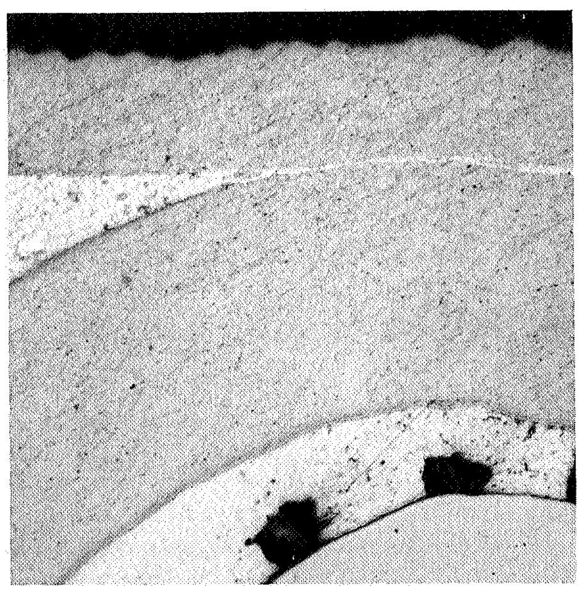
Figure 7 consists of photomicrographs of a transistor lead with a tubelet sectioned at several places. Photograph "A" shows a section between the hole and the end of the tubelet. Note the voids in the solder. Visual examination at arrow and other areas indicated a good bond between the solder, the lead, and the pad (50 times magnification after 3936 thermal cycles). Photograph "B" at 100 times magnification shows the cut across the tubelet, lead, circuit pad, and connecting solder. Voids exist between the tubelet and lead on one side. Photograph "C" is a view at 250 times magnification of the side containing some of the voids. Note the good bond between the solder at the pad and between the solder and both the tubelet and the lead. Photograph "D" is a view at 500 times magnification of a portion of the area in "C". This photograph again shows positively the good bond between the solder and both the lead and the tubelet.



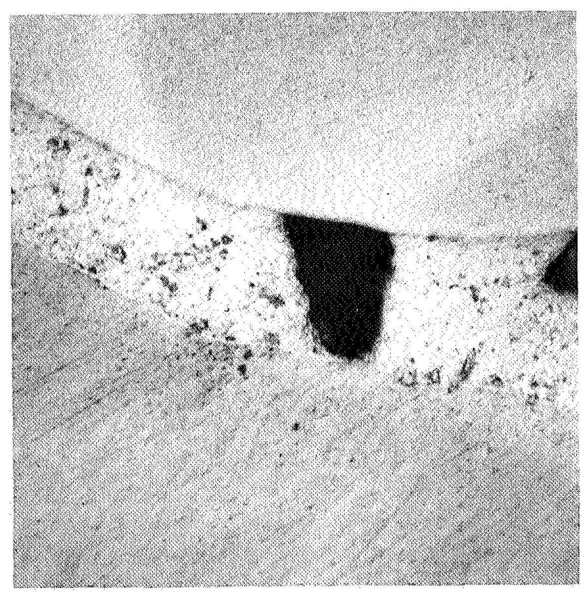
A
Magnified image copied at
85 percent



B
Magnified image copied at
85 percent



C
Magnified image copied at
85 percent



D
Magnified image copied at
85 percent

Figure 7. Transistor Lead with Tubelet Sectioned to Show Bonding

III. CONCLUSIONS

The following conclusions were derived from the accelerated test results:

1 The accelerated test reduces the evaluation time required for PC assemblies to less than two percent of earlier air thermal cycling test procedures.

2 The addition of a soft rubber pad between the component and the PC board substantially reduces solder joint cracking.

3 The addition of a copper tubelet over the end of the transistor lead in the solder joint substantially increases resistance to cracking. It is the most effective modification tested.

4 The addition of a crimped, welded, flanged, tubelet to the relay pin in the solder joint substantially increases resistance to cracking and is the most effective modification tested.

5 There is a definite need to improve the solder joints of resistors and capacitors in order to meet ATM requirements.

During the time required to complete this analysis, evaluation, and report preparation, a considerable amount of additional solder joint testing has been performed. The following preliminary results can be stated:

1 None of the four new solder alloys tested proved substantially better than 60 percent tin/40 percent lead.

2 The tests confirmed the superiority of the tubelet, soft rubber pad, thin spray coating of PC-22 conformal coating, and heavier solder on the joint.

3 The tests showed that a flanged tubelet slipped on the relay pin and soldered is more resistant to solder joint cracking. than a crimped, welded flanged tubelet.

The report on this new testing should be available in February 1968.

IV. RECOMMENDATIONS

The following recommendations are presented:

1. Additional solder alloys should be tested and combinations of promising modifications should be built and tested.

2. Modifications of solder joints for resistors and capacitors should be tested and evaluated.

3. Production ATM assemblies should be thermally cycled over the ATM limits with the accelerated testing machine to evaluate the effectiveness of implementing final designs.

4. Standard solder joint assemblies should be thermally cycled over the actual ATM temperature profile to give temperature correlation data with the accelerated testing already performed.

5. The major improvements outlined in the conclusions should be incorporated in the ATM assemblies to enable them to meet the specified environmental goal.